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Title:	The road goes ever on: status and outlook from the LANSCE Futures Workshop Series
Author(s):	Mosby, Shea Morgan
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Los Alamos NATIONAL LABORATORY

The road goes ever on: status and outlook from the LANSCE Futures Workshop Series

Shea Mosby, P-3

October 4, 2021

DMMSC Seminar

LANSCE's unique flexibility allows it to serve a variety of missions - and as a major recruiting center for LANL

Proton Radiography (pRad Facility)
- Dynamic radiography for defense programs and counterproliferation

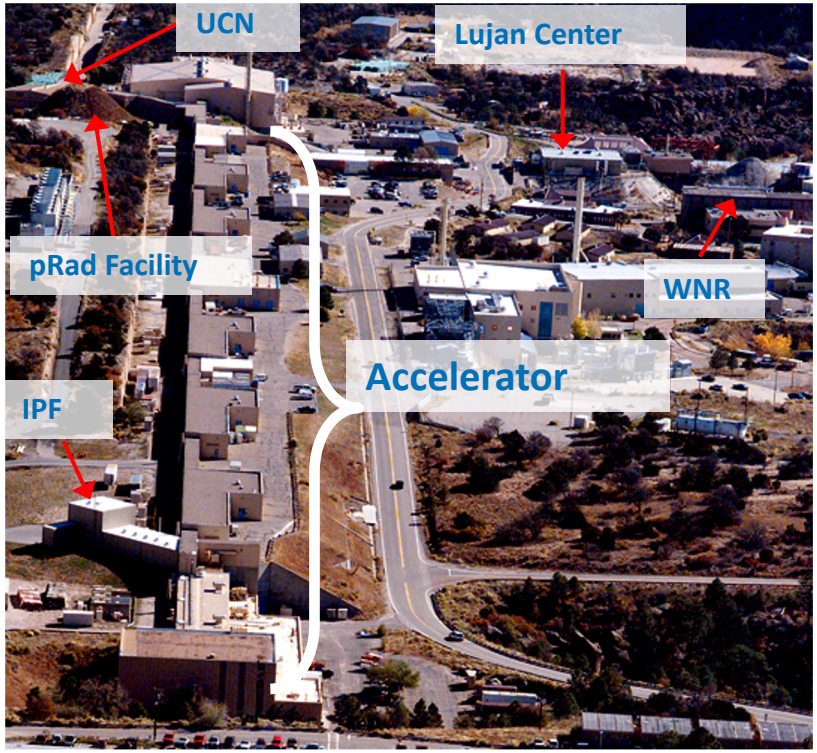
Lujan Neutron Scattering Center (Lujan Center)
- Neutron scattering and imaging for defense programs and nuclear energy
- Nuclear physics for defense programs

Weapons Neutron Research Facility (WNR)
- Nuclear physics for defense programs, counterproliferation, and criticality safety
- Electronics testing for industry and global security

Isotope Production Facility (IPF)
- Medical and other isotopes for the isotope program
- Short-lived isotopes for defense programs, non-/counterproliferation, and criticality safety

Ultra-Cold Neutron Facility (UCN)
- Unique probe for nuclear physics and NSF, possible future defense program uses

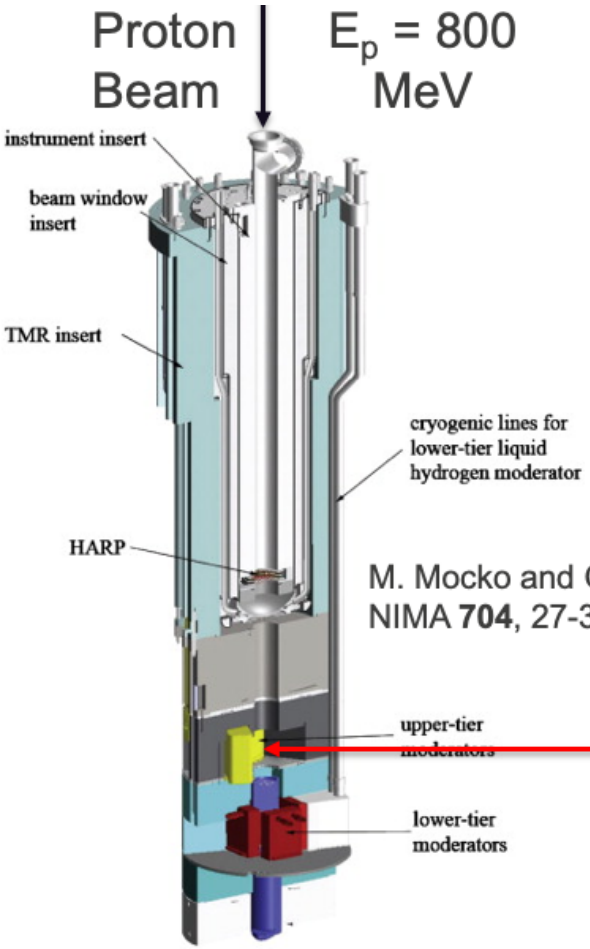
Area A
- *Future experimental possibilities*



100-800 MeV proton energies
six target stations (three neutron spallation targets)
sixteen beam lines

From M. Furlanetto, LA-UR-21-26361

A brief technical aside: how to make (and use) neutron beams

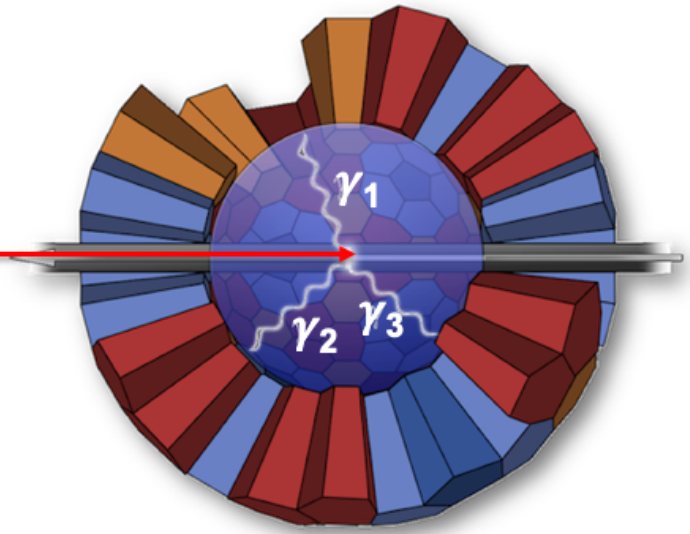


M. Mocko and G. Muhrer, NIMA **704**, 27-35 (2013)

-Neutrons of many energies made in one proton pulse

-Arrival time at experiment determined by neutron energy

https://t2.lanl.gov/fiesta2014/images/dance.png



L = 20.28m

LANSCE's flexibility motivates a discussion of the facility's future

- The LANSCE accelerator's inherent power, flexibility, and authorization basis enable an enormous range of experimental work.
- We see continuing need for this experimental work going forward.
- We therefore seek to develop the case for cutting-edge science at the (primarily NNSA-supported) LANSCE experimental stations to 2050 and beyond.
- The LANSCE Futures Spring 2021 Workshop Series opened this conversation.

Mission space available at various US accelerators

	LANSCE	Brookhaven	FermiLab	SNS
Proton Radiography	🟢	🟡	🔴	🔴
High Explosive Drive	🟢	🟡	🔴	🔴
Classified Experiments	🟢	🟡	🔴	🔴
Dynamic Plutonium Capability	🟢	🔴	🔴	🔴
Low-Energy Nuclear Physics	🟢	🔴	🔴	🟡
Isotope Production	🟢	🟢	🔴	🟡
Neutron Diffraction	🟢	🔴	🔴	🟢
Static Plutonium	🟢	🔴	🔴	🟡
Neutron Radiography	🟢	🔴	🔴	🟢
Energy-Resolved Tomography	🟢	🔴	🔴	🔴
Neutron Irradiation for Defense and Civilian Applications	🟢	🔴	🔴	🟡

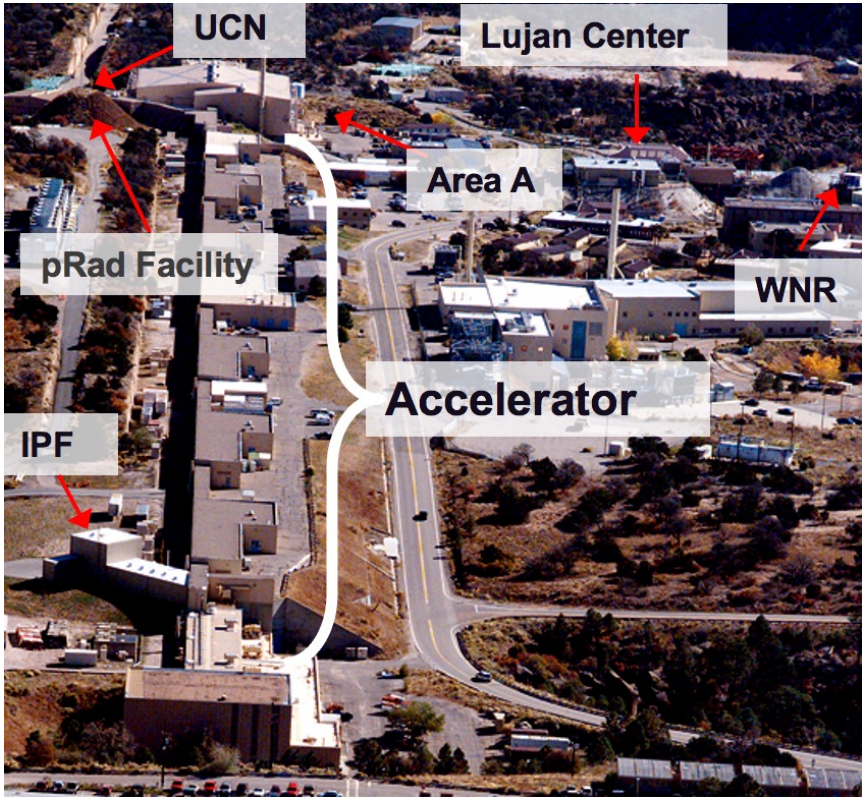
Snapshot of the LANSCE workshop series

- Reminder: the purpose of this series was to develop the case for cutting-edge science at the (primarily NNSA-supported) LANSCE experimental stations to 2050 and beyond. This feeds into the objectives of the LAMP and LANE concepts to secure long-term investment in LANSCE as a facility.
- The workshops themselves were a conversational opener, not an end-game.

Workshop breakdown:

1. Dynamic Radiography (April 5 – 6)
2. Scattering Science (April 21)
3. Nuclear Science (May 10 – 11)
4. Area A Futures (June 1 – 2)

- Workshops 1 – 3 focused on the connection between concepts and mission need.
- Area A was considered as a fielding location based on input from workshops 1 – 3.
- We will review content and highlights from these workshops.



Dynamic Radiography Workshop April 5 - 6

100+ attendees with technical, program, facility reps from key partners.

Driving the need: The workshop started off with talks from Bob Reinovsky and Guillermo Terrones, who laid out the mid-to-long term goals for the Advanced Diagnostics science campaign, the physics needs for W93 development.

Next generation proton radiography: time-of-flight imaging or increased depth-of-focus, as provisioned by a higher energy proton source, or a next-generation lensing solution were discussed, as well as a new high-gradient linac booster under development by AOT.

Multi-axis: higher dimensional information can resolve otherwise hidden data, multiple fields of view (and resolutions) are enabled. A 3-axis design could be valuable for mesoscale studies, and ARL has already demonstrated dynamic, 5-view X-ray CT reconstructions.

Drivers: PHELIX (pulsed power), Gun-driven actinides (powder or light gas) can provide non-vessel-driven drive for fundamental and focused experiments

Detectors and Analysis: The next generation systems will not be possible without next generation detector technology and analysis techniques

Multi-probe: A probe complementary to pRad can provide a second (or third) axis with unique attenuation properties enabling increased dynamic range and materials ID. This can be X-rays, electrons, visible light, or even neutrons. The source for these can be pulsed power, a custom RF electron linac (high TRL), or laser drive (low TRL).

Increased spatial resolution, depth penetration, and dynamic range, as enabled by higher energy and multiple probes, allows pRad to best meets the needs facing the lab today

3 GeV Proton Radiography

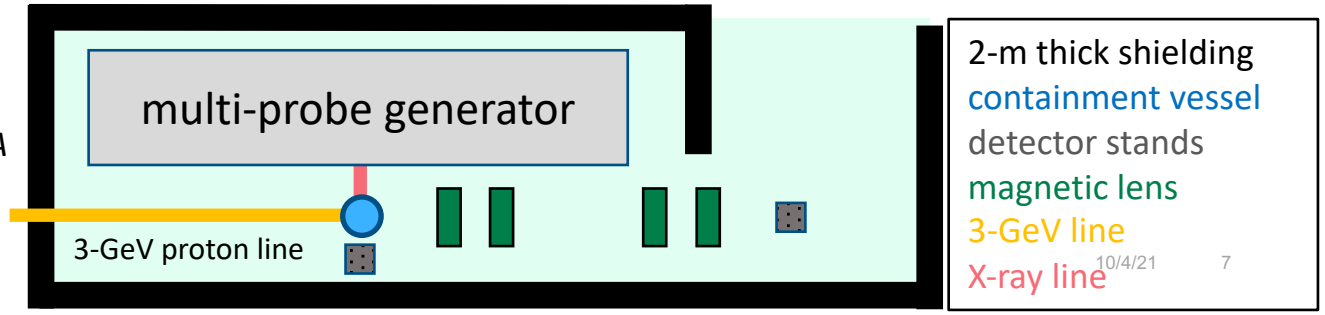
- Resolution scales according to $\delta x = L_C \, \theta \, \delta p/p$
  - At higher magnification, L_C (chromatic length) is reduced
  - At higher energy, θ (object scatter), and dp/p (proton momentum spread) are dramatically reduced
- This means: thicker objects and higher spatial resolution
- Small-scale Pu experiments with (1" - 2") thick, aluminum windows
- Will require a significant accelerator upgrade

Multi-probe Radiography

- X-ray source at 90º provides a second view with a complementary attenuation profile
- Different fields of view (i.e., different magnifications and spatial resolutions)
- Can also be an electron radiography source, for thinner targets
- Materials ID
- pRad is implementing a permanent pulsed-power 4-pulse X-ray system in 2022 that will probe for thinner materials than presently available, including wire bursts, aluminum powders, low-Z RMIs and RMI breakup, gas mixing and HE det products
- discussions of a next-generation (multi-pulse, higher-res, adjustable energy) source for the next-generation radiographic facility already under way

conceptual layout of Northern third of Area A w/ next-gen pRad

M. Freeman (P-1)



Scattering Science Workshop April 21

60 attendees with technical, program, facility reps from key partners

Materials Mission: John Sarrao provided an overview of the LANL materials mission and emphasized how LANSCE can contribute to DMMSC mission space.

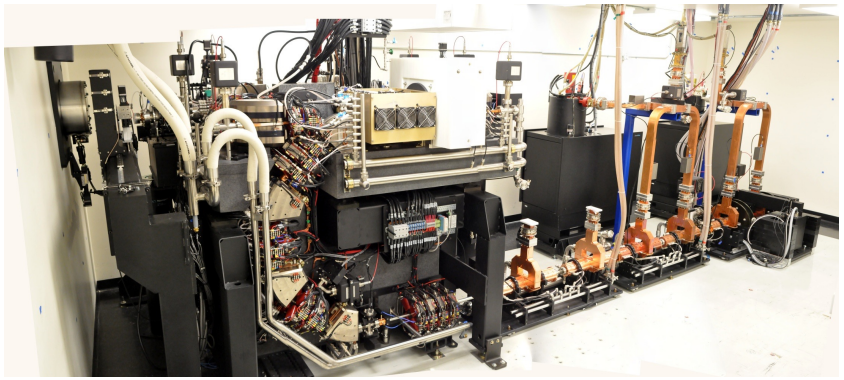
Existing Capabilities: Sven Vogel, Alex Long, Erik Watkins walked through existing beamlines and capabilities for scattering science at LANSCE.

Trends and Novel Concepts: external speakers provided perspective on where the Office of Science and scattering beamlines worldwide are going. SMARTS and HIPPO are competitive, and fairly modest (est. < $500k) upgrades for sample environments, multiprobe, and optimized backgrounds could maintain their place in the global scene.

Nuclear Energy and other LANL Programs: surveyed the perspectives from multiple programs. Observed that an optimized multi-probe version of FP5 in conjunction with proper sample environment for fuel capsules could provide energy resolved imaging and bulk characterization on atomic and capsule scale with service to several programs.

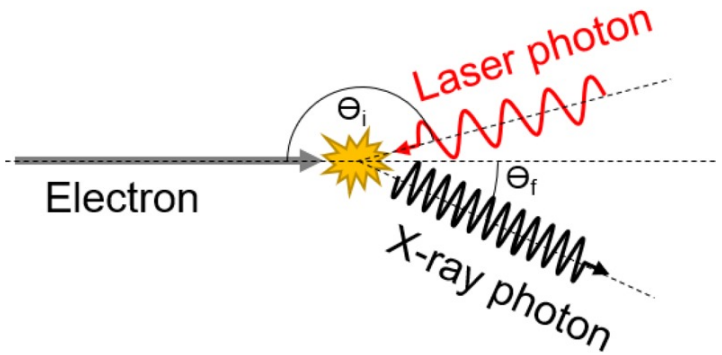
Weapons Program Connections: the operational overhead of classified operations at Lujan is high. A dedicated classified beam line with permanent infrastructure would allow for more efficient operations. A compact light source exploiting LANL's authorization basis could provide a very interesting capability.

A compact light source with LANL's authorization basis could be interesting



Lyncean Compact Light Source

- X-rays are widely accepted as a very useful probe for material properties
- Some work at APS in support of LANL materials program has happened – authorization basis issues limit progress.
- Many experiments don't require APS luminosity… could we do something local?
- Commercially available compact synchrotron source could enable this.
- Inverse Compton Scattering (ICS) allows shrinking a synchrotron to laboratory size while maintaining many of the beam properties.
- Looking at costs, potential siting locations now.



S. Vogel and D. Brown (MST-8)

Nuclear science workshop May 10 - 11

LANSCE Futures Spring 2021 Workshop Series

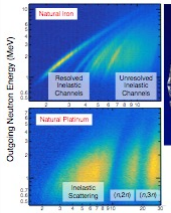
developing the technical case for cutting-edge science at the NNSA-supported LANSCE endstations to 2050 and beyond

LANSCE Los Alamos Neutron Science Center

Workshop 3 of 4: Nuclear Science

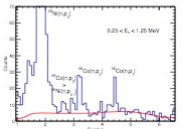
During the workshop, we solicit new ideas to enhance the current nuclear science capabilities at LANSCE and will discuss recommendations for further development options at endstations. Please register using this link by April 30th and for a talk's title submission if willing to present ideas on LANSCE endstation improvement to benefit your program. For any questions, email Hye Young Lee (hylee@lanl.gov) or Shea Mosby (smosby@lanl.gov).

Neutron scattering data taken @WNR (K. Kelly)

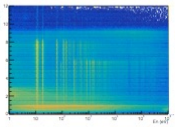


Prototype scattering array rendering (E. Bennett)

hotLENZ instrument for studying (n,z) reactions on radionuclides (H.Y. Lee)



(n,z) reaction measurement with a 6-day half life, ^{56}Ni @ WNR (S. Kuvin)



DANCE data for neutron capture on an isotopically enriched sample of ^{196}Pt (C. Fry)

E. Cidoncha is holding a barium fluoride crystal in front of DANCE @Lujan

Open WebEx Sessions on May 10th 2021

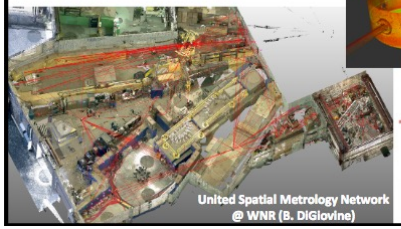
invited speakers:

Eva Birnbaum (Los Alamos National Laboratory)
Mark Chadwick (Los Alamos National Laboratory)
Tommy Cisneros (TerraPower, LLC)
Takeyasu Ito (Los Alamos National Laboratory)
Marian Jandel (University of Massachusetts Lowell)
Keegan Kelly (Los Alamos National Laboratory)
Rene Reifarth (Goethe University, Germany)
Jennifer Jo Ressler (Lawrence Livermore National Laboratory)
Greg Severin (Michigan State University)
Vlad Sobes (University of Tennessee, Knoxville)
Richard Van de Water (Los Alamos National Laboratory)
Etienne Vermeulen (Los Alamos National Laboratory)
Jack Winkelbauer (Los Alamos National Laboratory)
Sherry Yennello (Texas A&M University)
Michael Zerkle (Naval Nuclear Laboratory)

Classified Session on May 11th 2021 at NSSB conference room *(Max. occupancy: 60 people)*

invited LANL speakers:

Grant Bazan	(XTD-DO)
Christopher Fryer	(CCS-2)
John Gibbs	(XTD-PRI)
John Goett	(P-2)
August Keksis	(C-NR)
Paul Koehler	(P-3)
Sean Kuvin	(P-3)
Michelle Mosby	(XTD-NTA)
Shea Mosby	(P-3)
Christopher Prokop	(P-3)

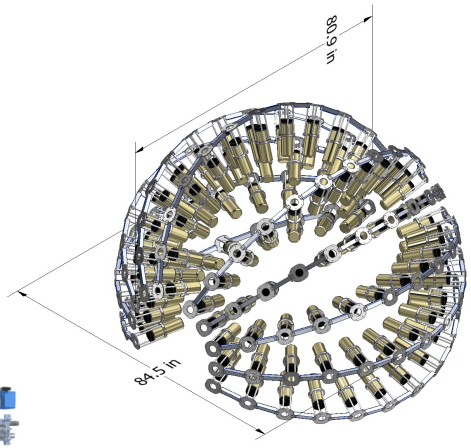


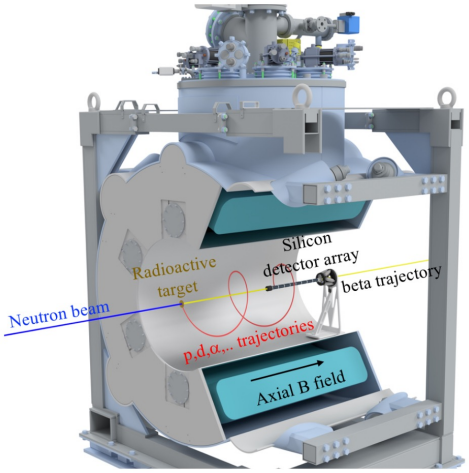
Device for Indirect Capture Experiments on Radionuclides (DICER) @Lujan (P. Koehler)

- 80+ attendees for open sessions including program reps from NNSA and beyond, and facility reps from key partners.
- Topics:
  - Partnership with national Isotope Production Programs for research isotopes
  - LLNL nuclear data perspectives
  - Criticality Safety
  - Partnership with universities and external facilities
  - Experimental futures in nuclear reactions
  - Theoretical developments in nuclear reactions
  - Fundamental science
- 42 attendees for in-person classified sessions including reps from design, radiochemistry, computational physics, experimental communities.
- Topics:
  - Implications of existing sensitivity studies
  - Nuclear science perspectives from LANL design communities (PAT, SAT, GS)
  - Radiochemistry perspectives on future measurements
  - Advances in computational physics
  - Experimental solutions to program needs
  - Applied physics and advanced diagnostics

Nuclear physics takeaway: clear path from the evolutionary to the revolutionary

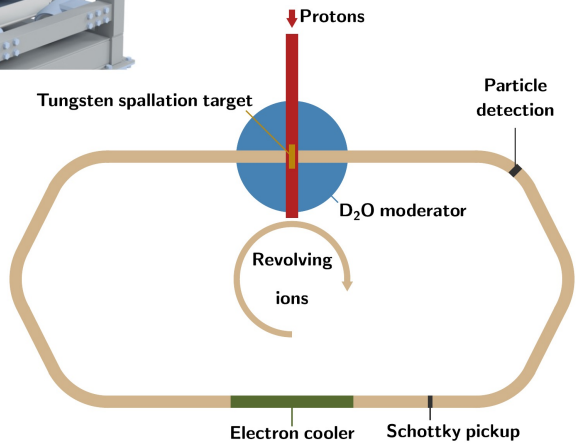
(right) Conceptual design for neutron scattering capability (K. Kelly)





(left) Schematic of solenoid spectrometer for radioactive isotope studies (H. Y. Lee)

(right) Neutron target conceptual rendering for long-term radionuclide measurements (S. Mosby)



- **Near term:** ***optimizations*** to Lujan and WNR facilities and endstations will enable next generation measurements for NNSA
  - Neutron scattering work is a known priority, development already begun
  - Initial measurements on radioactive isotopes exploit new Lujan target, will need enhanced WNR capabilities
- **Intermediate term:** ***partnering*** with LANSCE Isotope Production Facility (IPF) will be key
  - Increasing demand for radioactive isotope measurements require new capabilities in target production.
  - Purified research isotopes will become important – drives demand for a radionuclide separator at LANSCE.
- **Long term:** community discussion has begun regarding a ***completely new approach*** to radionuclide science
  - Concept would use LANSCE to drive a radioactive ion beam facility and "neutron target" to perform measurements that are currently impossible
  - Feedback between experimenters, program has begun to balance program impact and technical feasibility
- There is a clear ***feedback loop*** between "basic" science (reaction rates) and "applied science" (diagnostic development)
  - Multiple concepts for advanced diagnostics leverage expertise in experimental nuclear physics

Area A workshop June 1 and 2

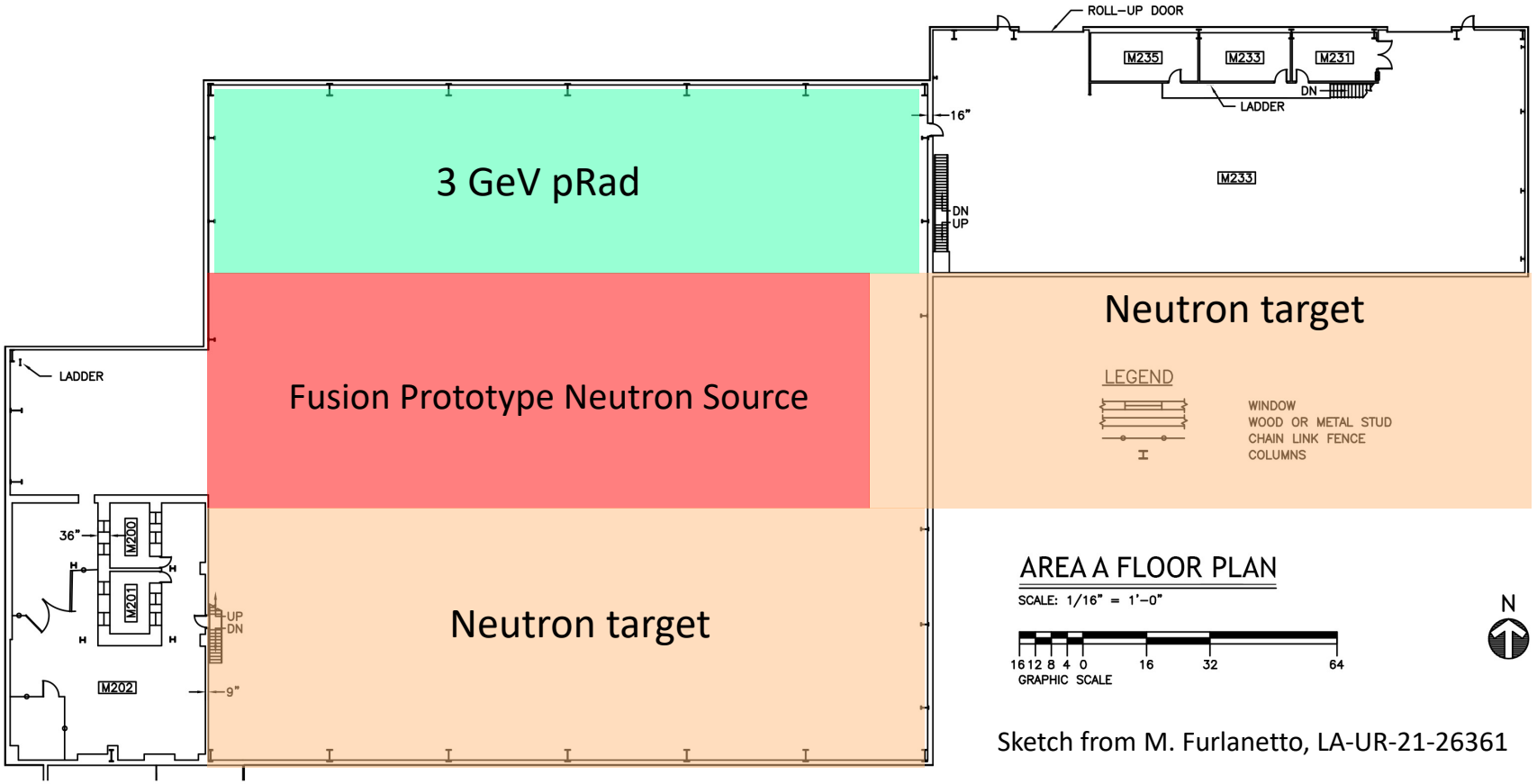
25 attendees, curated invite list for initial technical discussion on how concepts from first 3 workshops might interact.

- **Proton radiography:** discussed opportunities for additional pRad beamlines (e.g. in Area A) even at 800 MeV. Discussed booster linac technical option for delivering 3 GeV protons – question becomes where to park the booster?
- **Alternate radiographic probes:** discussion of electron linac (high TRL), laser driven (low TRL) sources which could add second dynamic radiography probe. Compact light source for static imaging discussed – again question of what the appropriate location is.
- **Basic and applied science:** brought up “burst facility” for exploring certain radiation effects experiments (more in a few slides) which would require a 3 – 5 GeV synchrotron, potential UCN upgrades, and low power protons for industry and GS effects testing.
- **High-current concepts:** discussion of involving IPF with discussion of future endstations – they can harvest isotopes from e.g. beam stops. Neutron target demands high power (>100 kW) and floorspace for the various subsystems. Fusion Prototype Neutron Source (FPNS) demands substantial beam power.
- **Formation of working groups:** assemble teams to discuss technical follow up, including interaction of burst facility and pRad futures, multiprobe pRad, and options for low power beam in Area A.

We're going to discuss a few topics in more detail

- Immense body of information contained in the workshops
- Multiple interaction points uncovered, driving follow-on work
- …so general awareness of current thinking may be useful
- The topics I'll go through started in each of the science workshops, started interacting in the Area A workshop
  - As a first brief topic: potential UCN upgrades require some thought on how NNSA/Office of Science would interact – team is off thinking about that now.

Area A: available space and one notional layout from the workshop

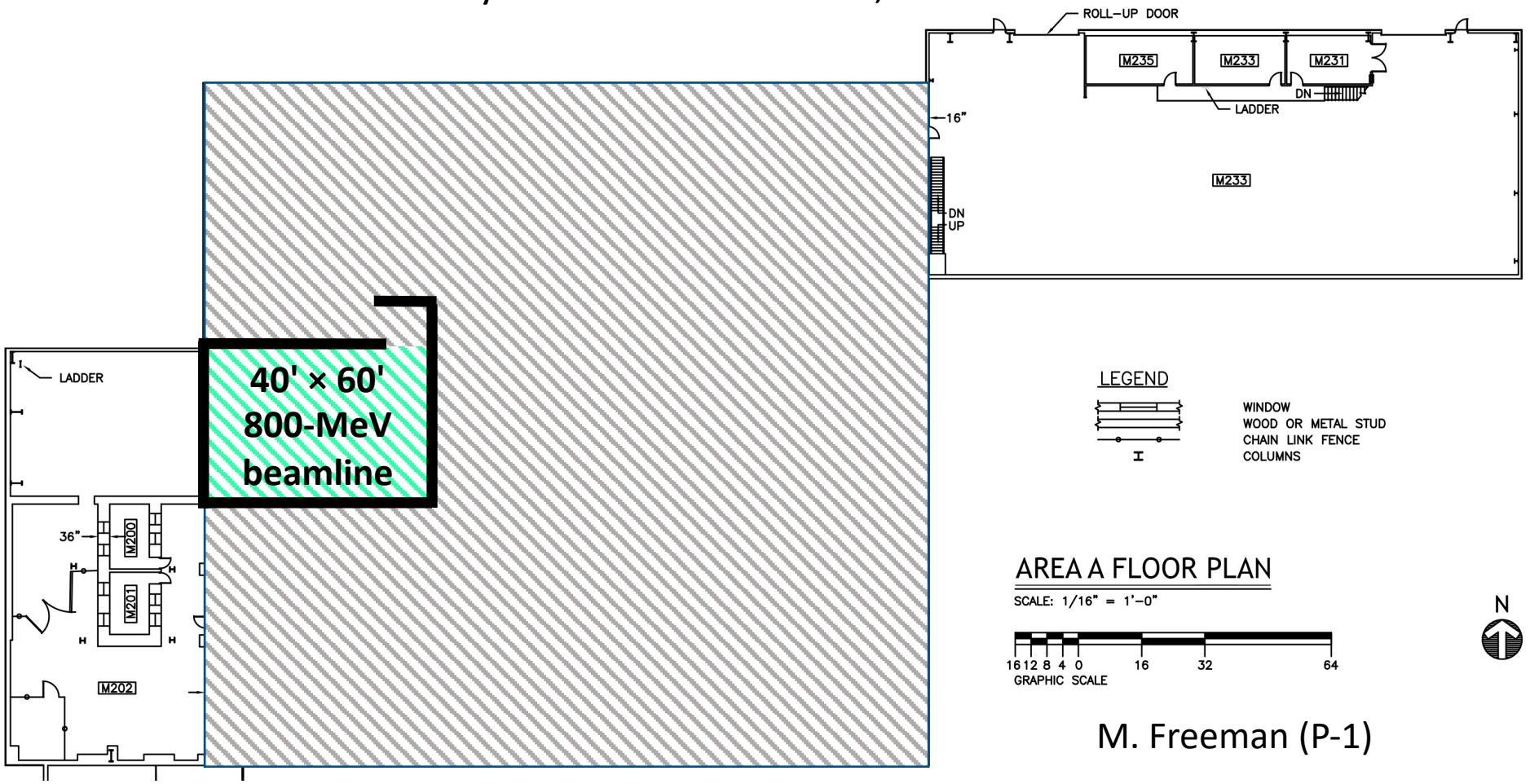


Sketch from M. Furlanetto, LA-UR-21-26361

- Some initial thinking has begun on utilization of Area A East as well
- This is ***notional*** – there are many caveats to consider

What a short term/low power use case might look like

- Restore low-current H+ to Area A (~$10M - ~$15M and 2 years)
- Once H+ is re-established to Area A, trivial to site a pRad beamline (and/or low power irradiation facility)
- Beam transport to the center is simpler, requires minimal transport
- This beamline can easily be moved elsewhere, later

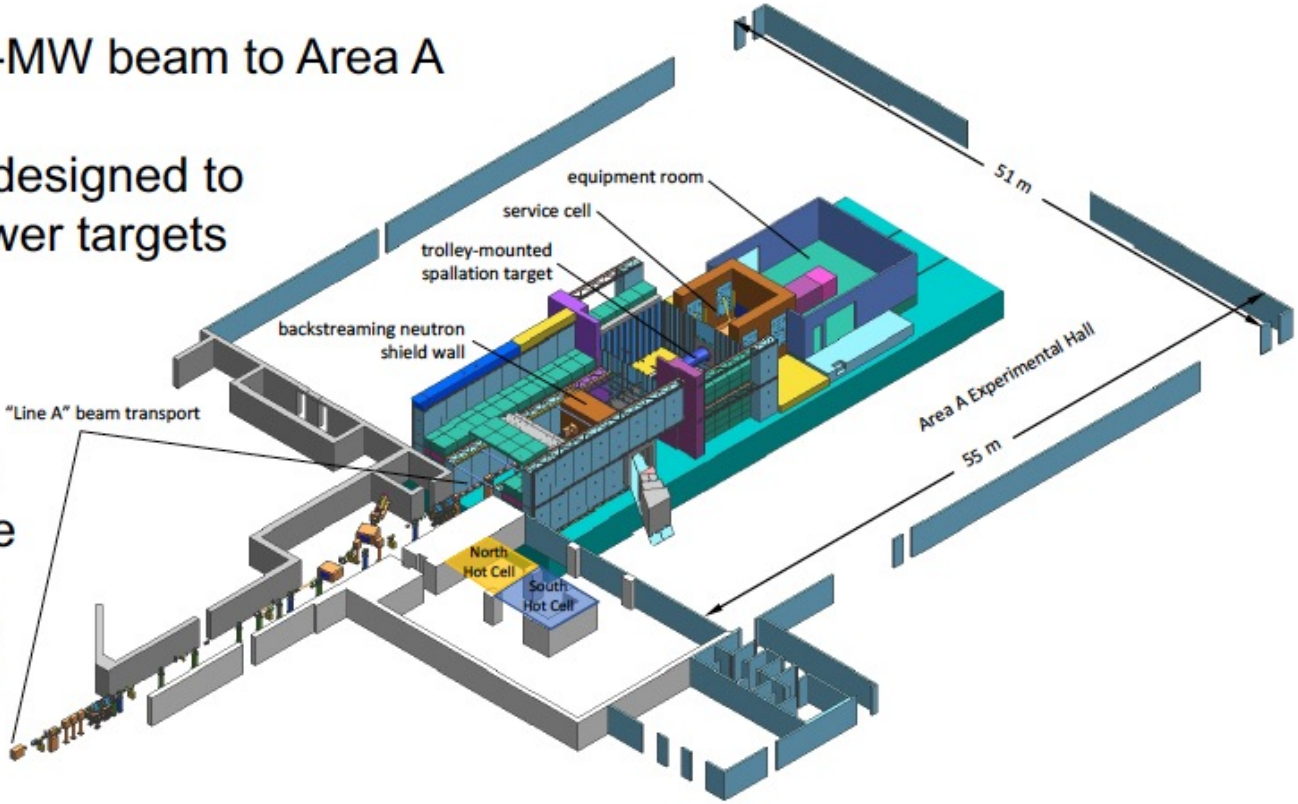


M. Freeman (P-1)

FPNS illustrates need to be thinking about logistics, coordination between concepts

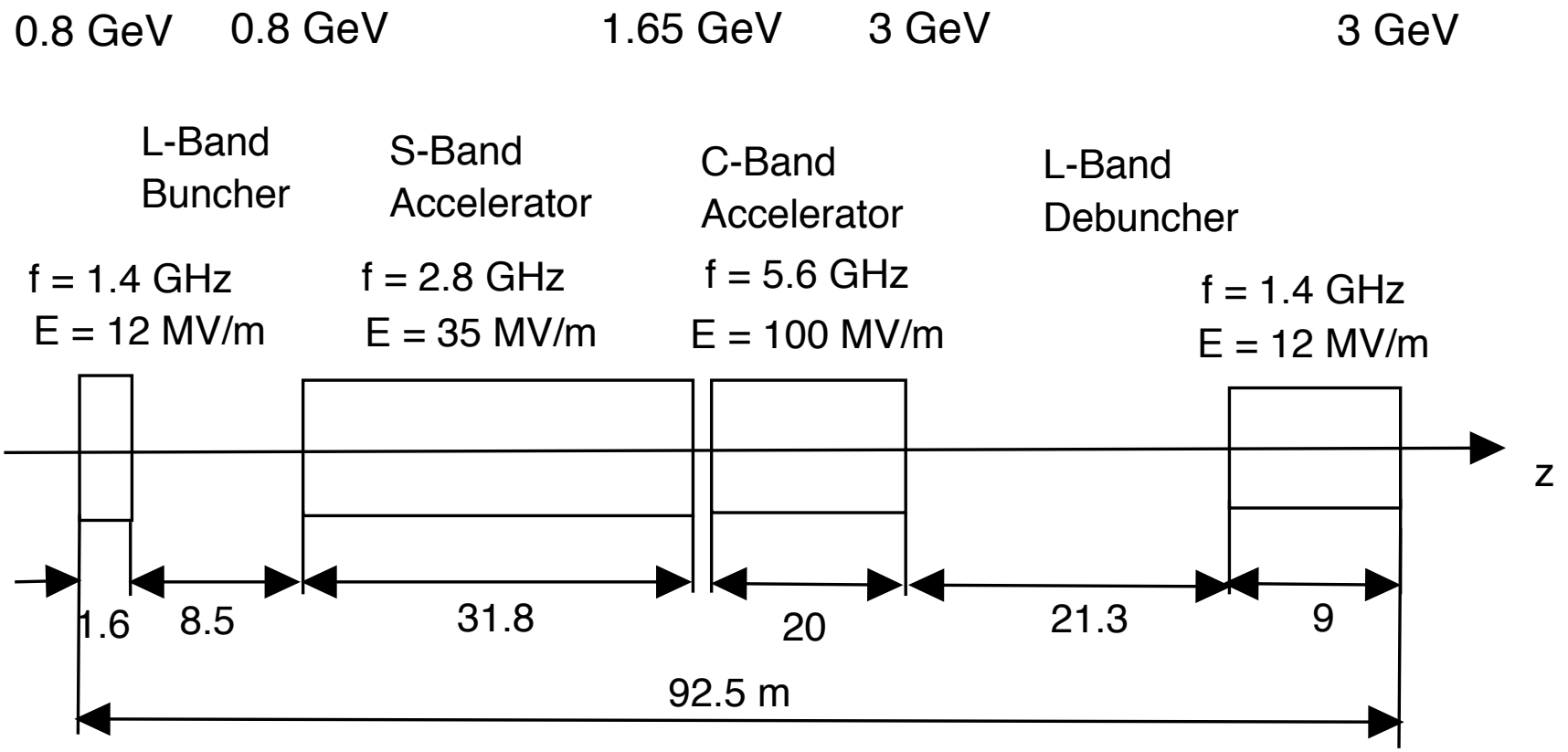
- FPNS would test components for the extreme environment expected in a fusion reactor
- Slide from E. Pitcher (P-DO) (below) shows how high power targets require careful thinking about infrastructure – illustrate the need for our Area A workshop

- LANSCE delivered 0.8-MW beam to Area A for a quarter century
- Experimental hall was designed to accommodate high-power targets
- Adjacent hot cells are available for use
- Central third of floor has 8-ft-thick base mat with magnetite concrete
- Infrastructure includes 2 30-ton cranes, 6 MW electrical power, water cooling, in-floor ducts



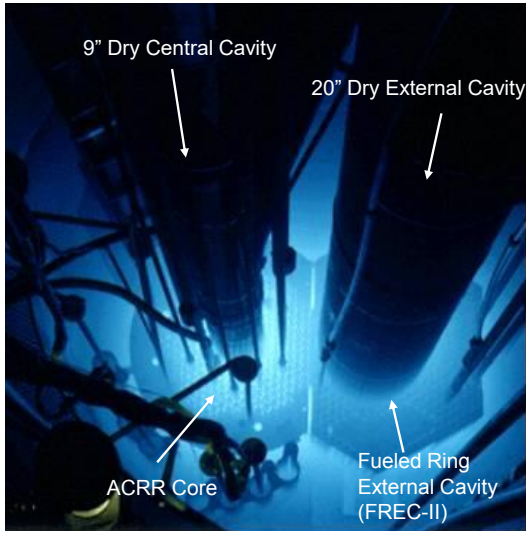
3-GeV Booster option for pRad needs some floorspace

- Info borrowed from Y. Batygin (AOT-AE)
- 92.5 m accelerator starting in switchyard spans most of Area A (Area A proper is ~55 m)
- Potential location therefore under discussion

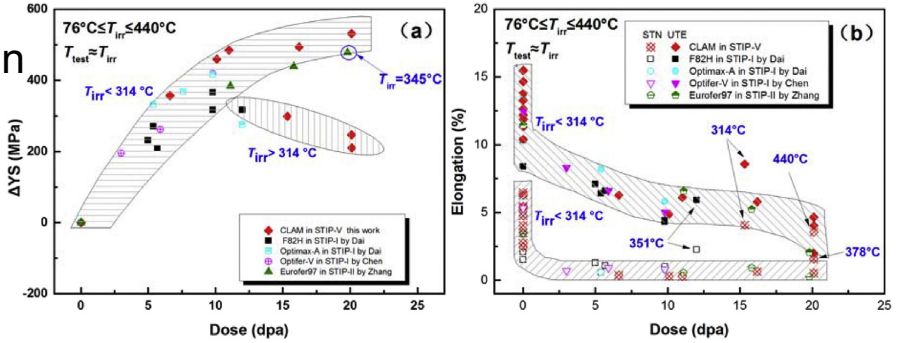


A burst facility offers a powerful complement to other facilities (if you can make it work)

- Driver: acute and chronic radiation dose can have profound effects on materials properties and electronics reliability
  - Point-defects
  - Embrittlement and hardening
  - Nucleation of voids and bubbles
  - Transmutation and activation
- Existing facilities are either oversubscribed or just barely capable of the fluences required to do interesting physics
  - Reactors have the fluence but are confined in many other ways
    - Dynamic experiment inside reactor core…
    - Time scales and spectra not as flexible as accelerator driven systems
    - Limited space for materials inside the core
- LA-UR-08-7486 looked a this problem using existing PSR – need 10x more dose



SNL ACRR & FREC operating at 2 MW steady-state. (SAND2017-8674). Energetic materials presumed unwelcome.



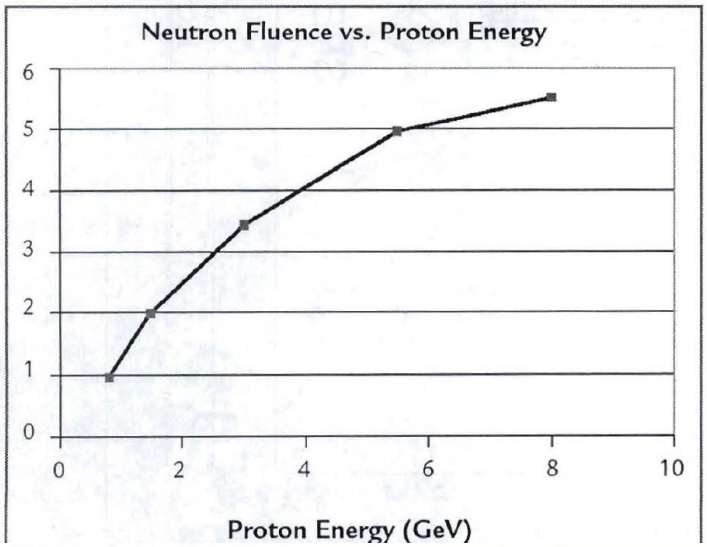
Survey of yield strength variance and elongation of RAFM steels exposed to neutron irradiation (Ge et. al. Journal of Nuclear Materials 468 (2016))

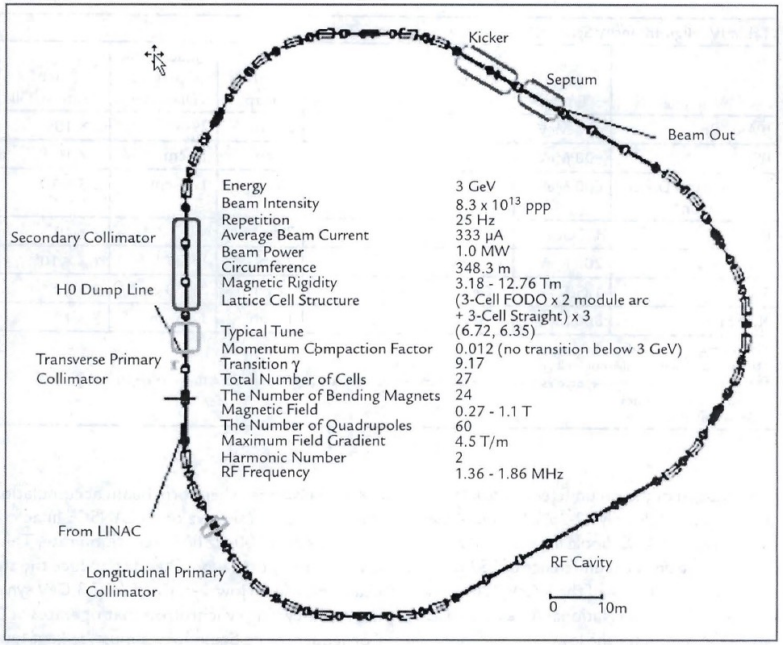
C. Prokop (P-3) and J. Goett (P-2)

Facility	Volume [cm3]	Intensity [n/cm2]	Pulse width[μs]	Target Mat.
SPR	32000	$5*10^{14}$	55	HEU
WSMR	785	$2*10^{14}$	45-75	HEU
SPEF	7623	$5*10^{13}$	5	LEU

A 3 - 5 GeV ring could provide needed performance, has potential synergy with pRad futures

- Near-linear gain in neutron production until ~4 GeV – so inject 800 MeV protons into a synchrotron and go up from there.
- Still need more protons in a pulse than existing PSR, so would need to design accordingly.
- Existing rings (e.g. 3 GeV Rapid Cycling Synchrotron at J-PARC) could provide a place to start thinking.
- …and pRad wants 3 GeV protons for its own future. Could one ring serve both purposes?
  - A ring could provide more protons/bunch than the booster
  - Dual purpose ring has technical challenges for injection/extraction
  - Working group to discuss trade space between booster linac, ring for pRad

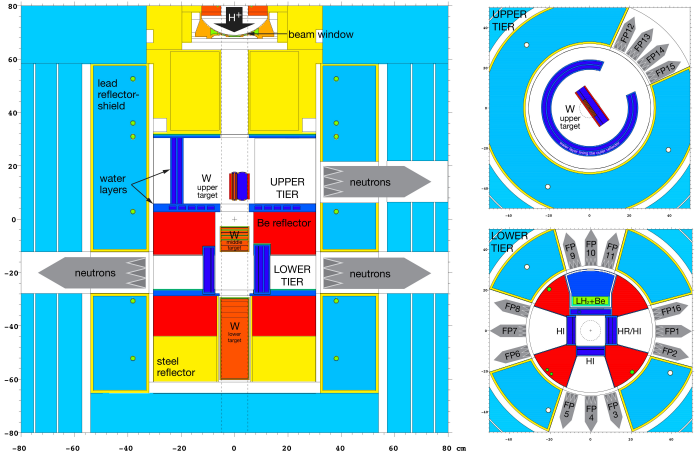




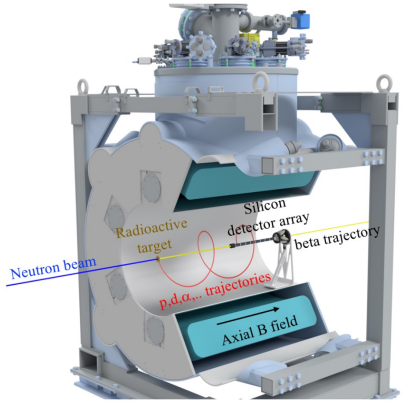
C. Prokop (P-3) and J. Goett (P-2)

Where things landed (1): evolutionary improvements now, and natural alignment with LANE

- Improvements already underway:
  - Multi-pulse x-ray source for pRad
  - Pu@pRad project
  - Vault-type room for unattended classified experiments at Lujan
  - Mark IV 1L Lujan target for enhanced nuclear physics
  - Short-lived isotope production, isolation, and study at both Lujan and WNR
- Possible options for LANE (or in addition to it)
  - H^+ beam to pRad for better resolution
  - Two-stage gun in Area C for enhanced experimental capability
  - Enhanced isotope production and separation for nuclear physics
  - Use of currently unused Lujan flight paths for scattering and/or radiography
  - Initial use of Area A with low-power proton beams for pRad and effects



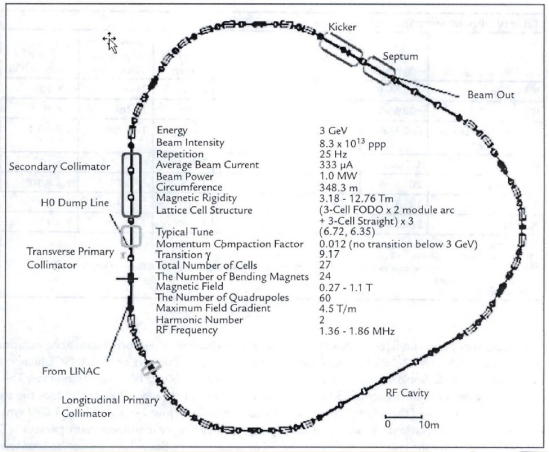
Mark IV 1L Lujan target



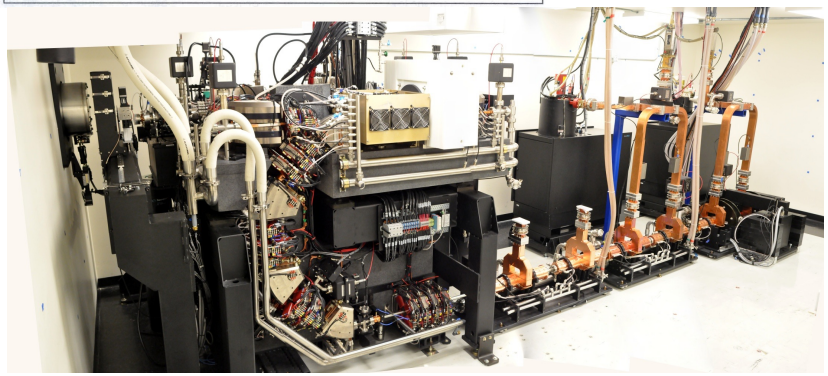
Proposed solenoid spectrometer for radioactive isotope studies

Where things landed (2): longer term (2030+), we are developing mission needs for more ambitious options

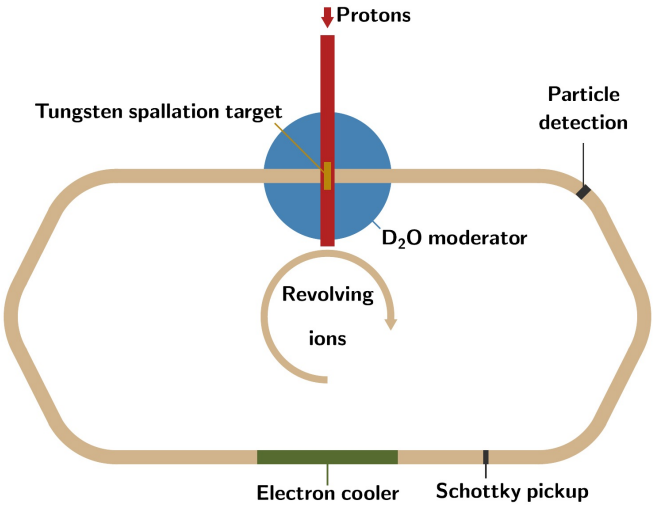
- Experimental area enhancements:
  - 3-5 GeV pRad
  - Neutron target
  - Burst facility
  - ICS x-ray source
- These upgrade paths do not conflict DMMSC/MaRIE concepts - they would occupy different locations at TA-53



JPARC 3 GeV proton synchrotron



Commercial ICS source



Neutron target for nuclear physics

State of play and the path forward

- All workshops are complete and the individual reports communicated to LUFD. Writing a global summary of the workshop series now.
  - These will feed the LAMP documentation which is in preparation, as well as conceptual development for LANE
- The quality and breadth of ideas presented at the workshops clearly demonstrates the need for LANSCE-based experimental science for the next several decades.
- Working groups have addressed certain key technical questions to feed next steps.
  - pRad energy upgrade and overlap with burst facility
  - Multi-probe pRad
  - Low current protons in Area A
- Certain broader collaborations formed during workshop preparation, are working toward follow-on investment to move the conversation forward.
  - Nuclear physics is pursuing follow-on reaction studies with partners across P, C, T, XCP, XTD
- Next: secure resources to follow the workshop recommendations for further concept development – *sustain the conversation*